Off-season Production of Primocane-fruited Red Raspberry Using Summer Pruning and Polyethylene Tunnels

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Abstract. The spring shoots of ‘Autumn Bliss’ red raspberry (*Rubus idaeus* L. var. *idaeus*; primocane-fruited type) were cut on 2, 16, 31 July and 15 and 30 Aug. with the objective of delaying fruit harvest into the off-season under mild winter climatic conditions. Cutting shoots in August delayed fruit harvest until February and April of the following year, but shoot growth was weak and fruit yield low (4.8 and 2.1 g/cane). July cuttings delayed harvest until October to January with acceptable fruit yield (63.5, 52.8, and 26.5 g/cane for 2, 16, and 31 July, respectively). The differences in cane height and total node and fruiting node count between the three cutting dates of July were small, but there was a constant decrease in leaf area per cane from the first to the third date and a sharp decrease in fruit yield from the second to the third date. Vegetative shoot growth was less affected than yield when summer cutting was delayed until the end of July to induce a later harvest. Fruit quality always reached acceptable standards. This study confirms the practicability of using summer-cutting of primocane-fruited red raspberries to induce off-season fruit production under protected cultivation in mild winter climates.

The economic advantage of off-season raspberry production for fresh market led growers to try new techniques for extending the production period. Earlier work on the effects of the environment on *Rubus idaeus* (Williams, 1959, 1960) outlined the major physiological processes related to the development of the raspberry plant in diverse environments. Several methods are now available, with various combinations for autumn and summer cultivars, that extend or delay the harvest period. Each production technique must be adapted to a particular region. In northern Europe, researchers developed various technologies using cold-treated canes of summer-fruited cultivars grown in pots in heated greenhouses

(Dijkstra and Scholtens, 1993; Faby, 1993; Lantin et al. 1971; Meesters and Pitsioudis, 1993). Although expensive, these techniques have been profitable due to the high off-season prices.

Oliveira et al. (1994) described a method to delay the autumn crop of the primocane-fruited cultivars in mild winter regions using late summer-cutting of spring shoots. With this technique the crop is delayed by cutting back the canes at ground level during summer. Primocane-fruited red raspberries must be used because of their ability to bear fruit on current-year canes. The extension of the cropping cycle is only possible in mild winter areas, where new growth and floral differen-

tiation can be maintained through September and October. The reduced light intensity and soil and air temperatures that occur during late fall seem to be the most limiting factors for crop productivity. The effects of the reduction in light intensity on yield were reviewed by Dale (1989) and the effects of temperature were studied by Hoover et al. (1989) and Privé et al. (1993) and can be used to interpret raspberry behavior under a particular cropping situation.

Our objective was to quantify the relationship between time of cane cutting, productivity, and quality characteristics of ‘Autumn Bliss’ raspberry grown in unheated polyethylene tunnels in a mild winter climate.

Materials and Methods

‘Autumn Bliss’ primocane-fruited red raspberries were grown on a sandy soil in a polyethylene-covered tunnel located 500 m from the sea on the southwest coast of Portugal (lat. 37°N) at 40 m above sea level under a mild winter climate. The tunnels were 3.5 m high, 9 m wide, and 60 m long and were opened up to 50% on both sides. Double rows of ‘Autumn Bliss’ were planted in Feb. 1991. The distance between rows was 1.6 m, and the distance between plants was 0.3 m. Rows were oriented north to south. A traditional “V” supporting system for primocane-fruited red raspberries was used. Irrigation and fertigation were computer-controlled, and insects and diseases were controlled following local commercial practices.

The crop was planted in February, and from March to July or August the plants were allowed to produce new canes. The five treatments consisted of cutting the canes at ground level at five dates: 2, 16, 31 July and 15 and 30 Aug. A randomized block design with four replications was used. Each plot consisted of three double rows (5.4 m long). The plants were 5 to 6 months old at the time of cutting. Cane density varied from 21 to 32 canes/m of row in the first and last cut, respectively. Owing to differences in cane density, 10 stools per plot were randomly selected and treated as experimental units. Cane height, node count, number of fruiting nodes, length of the fruiting section, total dry weight (leaves and canes), and total leaf area were recorded at the end of fruit harvest. Leaf area was measured with a leaf area meter (Mark 2; Delta-T Devices,

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Table 1. Effect of summer cutting dates on growth characteristics and fruit yield per cane of ‘Autumn Bliss’ red raspberry.

Cutting date	Growth characteristics					
	Cane ht (cm)	Nodes (no.)		Cane dry wt (g)	Leaf area/ cane (m²)	Yield/ cane (g)
		Total	Fruiting			
2 July	95.0	31.9	8.1	25.0	1.74	63.5
16 July	95.6	32.9	8.0	20.3	1.15	52.8
31 July	88.0	30.0	7.7	16.4	0.99	26.5
15 Aug.	63.3	21.0	3.4	10.5	0.49	4.8
30 Aug.	57.0	18.5	2.7	8.9	0.11	2.1
Significance						
Linear	**	*	**	**	**	**
Quadratic	**	**	**	**	**	**

*, **Significant at $P \leq 0.05$ and 0.01, respectively.

Fig. 1. Soil and air temperatures (in Celsius) and radiation (in micromoles per square meter per second) during the growing cycle of 'Autumn Bliss' red raspberry.

Cambridge, England). Soil temperature at 20 cm deep, air temperature at 150 cm aboveground, and photosynthetic active radiation (PAR) inside the tunnel were measured with the appropriate sensors every 10 s. These measurements were averaged hourly and recorded in a datalogger (DL2; Delta-T Devices). Heat units were calculated according to Hoover et al. (1989). Fruit were picked weekly, counted, and weighed. Fruit length, diameter, and weight were measured. The fruit analysis was done on 500-g samples from the second harvest date, which occurred on 28 Nov. for the plants of the first cutting date, on 13 Dec. for the second, and on 16 Jan. for the third. The August cutting dates did not produce enough fruit for a replicated analysis of quality. The color was measured on a 30-fruit sample, using a tristimulus color analyzer (chromameter, CR-200b; Minolta, Osaka, Japan) equipped with a head with a measuring area 8 mm in diameter. Measurements were recorded in $L^*a^*b^*$ CIE coordinates. Fruit (25

g) was blended with 100 ml of water, centrifuged, and filtered through a Whatman no. 4 filter paper. Then 10 ml of supernatant was added to 90 ml distilled water and titrated to pH 8.3 with 0.1 N NaOH. Titratable acidity was calculated as percent (in grams per 100 milliliter) citric acid. The juice pH was measured with a potentiometer (E/632, Metrohm SA, Herisau, Switzerland). The soluble solids concentration (SSC) was determined by refractometry (Atago PR-1; Atago Co., Tokyo), and the total reducing sugars were determined by spectrophotometry using glucose as a standard.

Biometric and quality results were subjected to analysis of variance. A regression analysis was performed, and the linear or quadratic coefficients were determined.

Results and Discussion

Cutting dates clearly influenced shoot growth, floral differentiation, and fruit yield of

primocane-fruiting 'Autumn Bliss' red raspberry (Table 1). July cutting dates induced little variation in cane height and node count but a sharp decrease in leaf area and fruit yield from the second to the third date. This result shows that vegetative shoot growth is less affected than yield when cutting is delayed within July to induce a later harvest. When shoots were cut on 15 or 30 Aug., there was a substantial reduction in cane height, leaf area, and fruit yield in comparison with July cutting dates (Table 1). Cutting the shoots in August reduced shoot height by 33% to 40%, fruiting node count by 58% to 67%, leaf area by 72% to 94%, and fruit yield by 92% to 97% compared to the first cutting date.

The August cuts delayed harvest until February and April, creating excellent marketing opportunities. However, this was done at the expense of plant growth and led to a poor fruit yield. It was clear that when shoots were cut too late in summer the decreasing temperature and solar radiation (Fig. 1) did not allow formation of sufficient vegetative growth to support an economic crop.

Air temperature inside the tunnel in July, August, and September was high, varying between 20 and 27°C. September to January was relatively cool, with the air mean varying between 12 and 20°C (Fig. 1). In an open field, the air mean was 1.8°C above average for 1967 to 1980 for July to September and 0.8°C below average for September to January (Instituto Nacional de Meteorologia e Geofisica, 1991).

Inside the tunnel, PAR was $>800 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ from July to September. During October there was a sudden drop to $\approx 300 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ in November to January. In the open field, the number of hours of sunshine from September to January was less than average (Instituto Nacional de Meteorologia e Geofisica, 1991). Normally, the decrease in radiation would be less than experienced during November and December.

The number of days from shoot cutting to peak harvest was similar for the three cuts of July. However, the harvest delays were longer than the intervals between the shoot cutting dates for shoots cut in August (Fig. 2). Thus, early in the season, a certain delay in shoot cutting will correspond to the same delay in

Fig. 2. Dates of cutting and number of days between cutting (C) and beginning of harvest (H0) and peak of harvest (H1) for five cutting dates of 'Autumn Bliss' red raspberry. The numerals show the number of days between each date. Cutting dates: 1) 2 July, 2) 16 July, 3) 31 July, 4) 15 Aug., and 5) 30 Aug.

fruit harvest. Although all July cuts induced cropping cycles of similar length, the accumulated temperature and PAR along the cropping cycle decreased considerably when shoot cutting was delayed (Table 2). The average daily PAR received by the plants was 31, 29, 26, 23, and 24 mol·m⁻² for the five cutting dates of 2 July to 30 Aug., respectively. However, the plants cut on 30 Aug. received the highest accumulated PAR because of their longer cropping cycle (233 days). The lower PAR and temperature received by the plants of the later cuts associated with a smaller leaf area may explain the significant reduction in fruit yield.

July cutting dates did not affect fruit diameter, length, and weight (Table 3). Only SSC and reducing sugar concentration clearly decreased between the first and the third cutting date. Color improved with advancing July cuts since fruit of the second and third cuttings were more deeply colored than those of the first cutting date. Fruit with a relatively high SSC but dull color were characteristic of the first cutting date; the reverse was the case for the third date. However, all fruit reached sufficiently high quality standards when compared with fruit of the same cultivar produced in June to July in another experiment where fruit weight was 4.2 g; SSC 7.0; and color 28.4,

19.9, and 21.7 for L*, h°, and C*, respectively (Oliveira, 1994).

During the shoot growth period of July cuts (July to October) the daily air mean was >15°C (Fig. 1), which is considered adequate for red raspberries (Fernandez and Pritts, 1994) and may explain the similar cane height and node count induced by these cutting dates (Table 1). The pronounced decrease of PAR from November onwards (Fig. 1) may have contributed to the reduction in yield of the 31 July cut compared to the first two cuts. From the second to the third cut, the decrease in cane height was 8%, 9% per cane in leaf area, 50% in fruit yield, and 52% in sugar concentration. The sharp decrease in yield of the third cut, associated with a decrease in PAR during the fruit growth period, is in agreement with the findings of Braun and Garth (1984), who showed a 44% reduction in yield when raspberry plants received 63% shading. Cutting the canes on 2 and 16 July induced sufficient vegetative growth and fruit yield; cutting on 31 July resulted in sufficient vegetative growth but insufficient fruit yield. Cutting in August produced extreme low vegetative growth and fruit yield.

The fruit yield of 64 and 53 g/cane, equivalent to 1.3 and 1.2 kg·m⁻¹ of row, produced by the first two cutting dates was harvested mainly in November and December when market opportunities are good and prices high. These yields were good because in June and July of the following year the same plants yielded ≈40 g/cane with a density of 48 canes/m⁻¹ of row, which is equivalent to 1.9 kg·m⁻¹ of row (Oliveira, 1994).

Our study confirms that there may be a good prospect for applying summer-cutting techniques in areas with cool summers and mild winters, as on the south coast of Portugal. Altering the cutting date within certain limits allows the extension of the harvest season, but available light and temperature are limiting

for production during the most unfavorable period. Under our experimental conditions, when summer-cutting is done before the end of July the productivity and quality of 'Autumn Bliss' are commercially acceptable and harvest is delayed by 3 months compared to a standard open-field crop. Further research on methods to improve photosynthetic leaf area index and to avoid excessive air temperatures inside the tunnels during summer are needed. Information on the accumulation and the partitioning of carbohydrates within the plant during the annual growth cycle also is needed for a better understanding of red raspberry performance under limiting conditions of temperature and PAR.

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Table 2. Effect of summer-cutting date on the length of the growth period of 'Autumn Bliss' red raspberry and the corresponding heat units (Σ temp) and photosynthetic active radiation (PAR) (Σ PAR).

Cutting date	Growth period (days) ^a	Σ temp (°C)	Σ PAR (mol·m ⁻²)
2 July	169	2203	5263
16 July	164	2057	4719
31 July	169	1956	4306
15 Aug.	182	1773	4147
30 Aug.	233	1926	5490

^aFrom shoot cutting to peak harvest.

Table 3. Effect of the first three cutting dates on fruit quality of 'Autumn Bliss' red raspberry.

Variable	Cutting date ^a			Significance	
	2 July	16 July	31 July	Linear	Quadratic
Diameter (cm)	2.0	2.0	1.9	NS	NS
Length (cm)	1.9	1.9	1.9	NS	NS
Weight (cm)	3.8	4.1	3.6	NS	NS
SSC ^b	8.5	8.1	8.1	**	**
pH	2.9	3.0	2.7	NS	*
TA ^c (g/100 ml)	1.5	1.6	1.4	NS	NS
Sugar (g/100 mg)	5.3	3.4	2.1	**	**
L*	23.3	27.0	27.8	**	**
h° ^y	16.5	20.6	20.8	*	NS
C* ^y	16.2	19.6	17.4	NS	NS

^aThe fruit for analysis were sampled on 28 Nov., 13 Dec., and 16 Jan. for the cutting dates 2, 16, and 31 July, respectively.

^bSSC = soluble solids concentration, TA = titrable acidity, h° = hue angle (arctangent b*/a°); C* = chroma {[(a*² + b*²)^{1/2}] }.

NS, *, ** Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.